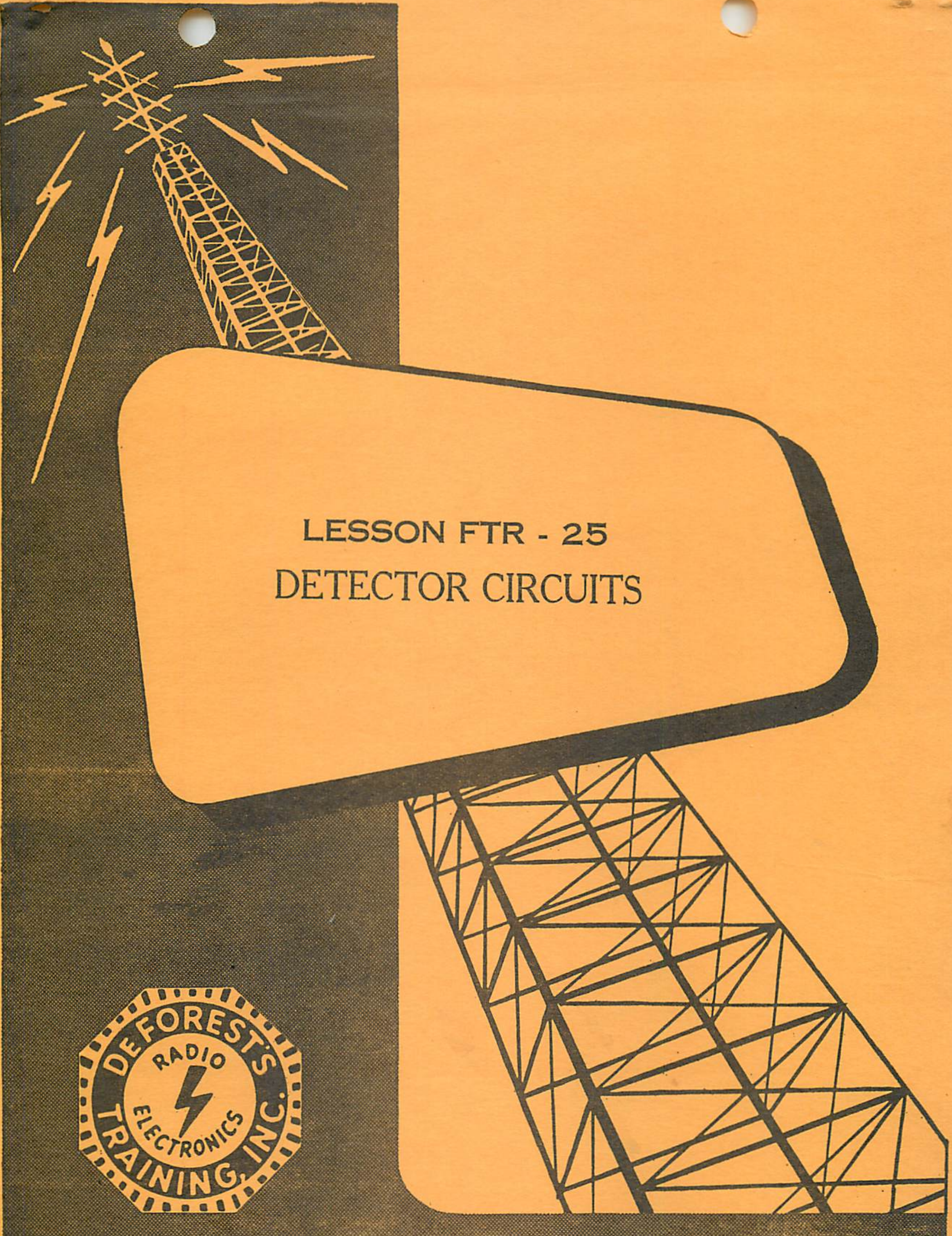

LESSON FTR - 25

DETECTOR CIRCUITS

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LESSON FTR-25

DETECTOR CIRCUITS

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Opportunity comes like a snail and once it has passed you, it changes into a rabbit and is gone. What is opportunity? It is a chance to do something, to give something, to achieve something, to climb out of the rut. To be somebody of value in the world. Opportunity is life itself.

-- Arthur Brisbane

Before going into the practical details of the various types of Radio Receiver circuits, we want to explain the action of all the main units and therefore will spend this Lesson on detectors.

The earliest broadcast radio receivers used no tubes but had a detector made of a sensitive metal such as Galena, Silicon or Carborundum. A fine wire point, known as a "Cat Whisker", was moved around the surface of the crystal until a sensitive spot was found.

The action can best be explained by the circuit of Figure 1 where we have a crystal detector in a circuit with a battery and sensitive milliammeter. Connected as shown, the meter will register the current in the circuit but, with the crystal connections reversed as indicated by the dotted lines, the meter will read little if any current.

This action of the meter tells us, with current in one direction, the crystal offers a low resistance but with current in the other direction, has an extremely high resistance. This principle holds for all types of detectors or rectifiers and can be thought of as the change in current when an equal voltage is applied to unequal resistances.

In Figure 1 for example, the battery voltage and the circuit remain the same but the value of current is changed by reversing the connections to the crystal. The change of current therefore must be caused by the difference of resistance in the crystal.

VACUUM TUBE RECTIFIER

To make use of this principle the earliest vacuum tubes had but two elements, the filament or cathode and plate, and were therefore called "Diodes". A circuit with a tube of this type is shown in Figure 2 and, when the filament is heated, electrons are drawn to the positive plate. When the plate is negative, the electrons are repelled and driven back to the filament.

Because a flow of electrons is considered as a current of electricity, there will be current in the plate circuit, only when the plate is positive. Connecting a diode tube as in Figure 2, during the alternation in which the upper wire is positive there will be current in the direction of the arrows. ① During the next alternation, the plate will be negative, the electrons will be repelled and therefore there will be no plate current.

Although connected to an A.C. supply, current in the A.C. supply circuit of Figure 2 will not be alternating. While changing in value with the changes of A.C. voltage, the current will be in the direction of the arrows only and is called a pulsating direct current.

That is the action of the present rectifier tubes which are used in the power supplies of Television, Sound and Radio equipment. However, we are interested in detectors at this time and the diode tube of Figure 2 will produce a detector action like the crystal of Figure 1.

Perhaps the best way to see the entire action is by drawing a curve like that of Figure 3. Imagine we have the arrangement of Figure 2 but with an ammeter and voltmeter in the plate circuit. Instead of an A.C. supply, this time we have D.C. arranged so that we can make the plate either negative or positive, in respect to the filament, at any desired voltage.

Following the general plan used for three element tubes, we plot the plate current against the plate voltage. No actual values are shown because we are interested only in the general shape of the curve.

Starting over at the left, with negative plate voltage, the plate current is zero. As the negative voltage is reduced, the current still remains at zero. As soon as the plate voltage is reversed and made positive, there is plate current and, as the positive voltage is increased, the plate current increases also. Notice however, the plate current does not increase in exact proportion to the voltage. It starts slowly but increases at a faster rate to form the bend in the lower part of the curve.

Keep this in mind as we will have more to say about it later. Notice also, the similarity between this curve and the grid voltage-plate current curve of a three element radio tube.

MODULATION

To fully understand the detector action, you must have a clear idea of the form of radio wave reaching the receiver. In case you have forgotten, Figure 4 at A, represents the high frequency carrier wave produced by the oscillator at the Broadcasting Station and sent out from the transmitting antenna.

For the Broadcast band, the frequency of this wave will be from 550,000 to 1,550,000 cycles and, as we explained in the earlier Lessons, our ears will not respond to these high frequencies. Notice also, the carrier waves all have equal amplitude and will not produce any sound even if tuned in with a good receiver.

Audio frequency, or sound waves, having a lower frequency, change less rapidly and usually are of an irregular shape. The curve at B, Figure 4 is an example of a simple form of sound wave.

In order that the high frequency carrier waves will transmit signals, they are modulated and a modulated carrier wave is simply a combination of waves A and B, Figure 4, which can be shown by the form at C.

Notice here, the carrier wave of A is still used and has the same frequency but the amplitude of the waves is varied so that a dotted line, drawn along the wave crests, has the shape of the audio wave at B. The modulated carrier wave of Figure 4C is the form which reaches the detector the purpose of which is to change the wave back to the audio form of B.

As its name implies, the carrier wave is used to carry the audio frequencies from the transmitting to the receiving station and the detector, or demodulator, changes the modulated carrier waves back to the low frequency audio waves.

CHARACTERISTIC CURVES

To follow a modulated carrier wave through a three element radio tube we are going to use the characteristic curves explained in an earlier Lesson on tubes. In Figure 5, we show the usual grid voltage plate current curve and you will see there is a plate current of 3 MA. with zero grid voltage. As the grid is made positive, the plate current increases but, with the grid made negative, the plate current is reduced, dropping to zero at about 5-3/4 volts. Notice here, the lower part of the curve is about the same as the positive half of Figure 3.

To show the action when an alternating voltage is applied to the grid, we have drawn the sine wave in the upper center of Figure 5. Reading down to the grid voltage scale, you will see the A.C. has a maximum value of 2 volts.

Starting at the top of this curve, with 0 grid voltage, there will be a plate current of 3 MA. Following the curve down, it goes to 2 volts negative which, as shown by the grid-voltage-plate current curve, reduces the plate current to 1-1/4 MA.

Then, as the voltage curve comes back to zero, the plate current increases to 3 MA. but when the voltage curve reaches 2 positive, the plate current has increased to 4-3/4 MA.

Plotting these values, we draw the curve at the right and find it has the same general shape as the voltage curve. Or saying it in another way, an alternating voltage applied to the grid will produce an alternating variation of current in the plate circuit.

The important point to notice here is that the equal alternations of grid voltage produce equal changes of plate current.

Starting at zero grid voltage with a plate current of 3 MA., 2 volts negative reduces the plate current 1-3/4 MA. In the same way, when the grid was 2 volts positive, the plate current was increased 1-3/4 MA., from the 3 MA. at zero grid voltage.

If the voltage wave of Figure 5 is like that of Figure 4-A, these changes of plate current will take place so rapidly that no sound will be heard in the speaker. From an electrical standpoint, as these rapid changes are equal, the average plate current will not change and therefore will not operate any sound producing device.

The trouble with conditions as shown in Figure 5 is caused by the fact that the grid is positive part of the time. When the grid is positive it allows current in the grid circuit and causes distortion of the wave.

To remedy this trouble, in Figure 6 we have placed a 3 volt negative bias on the grid but, to keep the values about the same as in Figure 5, we still have a plate current of 3 MA. at zero grid voltage. The negative grid voltage is secured by the use of a C battery or grid bias resistor.

Now, comparing Figures 5 and 6, you can see that like values of grid voltage produce like changes of plate current. Here however, the grid voltage varies from 5 negative to 1 negative and is never positive while the average value of plate current is lower.

We want you to notice here that in both Figures 5 and 6 the signal voltage varies from 2 volts positive to 2 volts negative. In Figure 6, with the steady 3 volts negative of a C supply, adding the signal voltage makes the grid voltage vary from 2 neg. plus 3 neg. or 5 negative to 2 pos. plus 3 neg. or 1 negative.

Every change in grid voltage can be carried to the characteristic curve, as shown by the heavier lines, to find the corresponding value of plate current. Notice however, in both Figures 5 and 6, we are operating on the straight part of the characteristic curve keeping above the bend at the lower end. Increasing

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the plate voltage lengthens the straight part of the curve and therefore the voltage swing of the grid can be increased without causing distortion.

IDEAL DETECTOR

If we could build a tube, or other device, having a perfect straight line for the entire length of its voltage-current characteristic curve we would have a perfect rectifier. The curve of the diode tube, shown in Figure 3, comes close but the slope of the curve changes at the lower end. This change in slope is found in all present day detectors and, to a great extent, determines the amount of distortion.

DIODE DETECTOR

Perhaps the most common method of demodulation in present day receivers is the "Diode Detector". This type of detector makes use of a two element, or diode, tube and for a simplified explanation of the action, we will again refer you to Figure 2.

For this explanation however, we want you to assume a load in series with the lower lead between the filament and the A.C. supply. This load can be assumed as a resistor and we will refer to it as R1. It will possibly help you to follow our explanation by actually drawing this load, R1, on Figure 2.

As R1 is in series with the tube, all the current in the circuit must pass through it and thus there will be a voltage drop across it in proportion to the current and the ohmic value of the load. With an A.C. supply, there will be current only in the direction of the arrows and the voltage drop across R1 will be in the form of pulsating D.C. In other words, this voltage drop across R1 will be similar in shape to the positive alternations of the applied A.C.

Now, if a condenser of the proper value is placed across, or in parallel to, R1 it will charge on the peaks of these voltage pulses and discharge as the voltage decreases. This will tend to maintain a steady D.C. voltage across R1 and it may help you to think of the condenser as filling in the gaps between the positive alternations, by its charging and discharging action.

The above is a simplified explanation of what takes place in a diode detector but, to establish the idea more firmly in your mind, we will use the same circuit again, with R1 and the condenser. This time however, we will assume the modulated carrier of Figure 4C is applied as the A.C. source.

Analyzing the wave of Figure 4C, you will notice that the peaks vary in amplitude. Thus, when applied to the plate of Figure 2, the peak values of current in the circuit will also vary and cause the peak values of voltage drop across R1 to vary in accordance with the input voltage. Without taking the condenser action into consideration, the wave form across R1 will be similar to the positive alternations of the carrier of Figure 4C with varying degrees of amplitude, dropping to zero after each alternation.

However, by the charge and discharge action explained above, the condenser keeps the voltage from dropping to zero and tends to maintain the voltage drop across R1 at the peak values. The result is a final wave form similar to the broken line shown across the tops of the positive alternations of Figure 4C.

This broken line conforms to the shape of the original sound wave of Figure 4B and thus the above circuit has achieved the purpose of a detector which is to separate the original sound from the carrier. You can see however, in order to accomplish this action, the condenser should be large enough to smooth out the high frequency variations but not be so large as to effect the audio variations.

In practical diode detectors, it is generally found necessary to provide a filter with the arrangement shown in Figure 7. We want you to assume the combinations of C1-L1 and C2-L2 form the primary and secondary of the last I.F. transformer in a superheterodyne receiver, resistors R1 and R2 form the load while condensers C3 and C4 give the needed condenser action and at the same time, with R1, form a high frequency filter.

The action here is the same as previously explained for Figure 2 and, in Figure 7, assuming L2 as the voltage source, when the plate is positive in respect to the cathode, the current will be from the plate, to cathode, to ground and, to complete the circuit, from ground up through R2 and R1 to the lower end of L2.

The rectified voltage therefore appears across R1 and R2 but, as R1 is part of the filter, the audio voltage across it is lost and the useable A.F. is that which appears across R2. This signal is then applied, through a coupling condenser, to the grid of the first A.F. amplifier tube. A filter, like that in Figure 7, reduces the useful output voltage by the ratio R2/(R1 + R2) as a result of the voltage drop in R1. Due to this ratio, it is common practice to make R2 several times the value of R1.

③ The diode method of demodulation has the advantage over other methods in that its characteristic more closely approaches

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that of the ideal detector and thus it produces less distortion. It has the disadvantages that it does not amplify the signal and draws current from the input circuit thereby reducing its selectivity.

However, because the diode method of detection produces less distortion and permits the use of simple automatic volume control circuits without the necessity of an additional voltage supply, it is most widely used in broadcast radio receivers.

GRID BIAS DETECTORS

③ ② A second method of demodulation uses a three element tube with a negative grid bias and is called, "Grid Bias Detection", "Plate Detection", or "Plate Rectification".

To understand the action, in Figure 8 we again have a grid voltage-plate current curve, similar to those already explained but, this time, have used values of B and C voltage which cause the tube to operate on the lower bend of the curve.

In our former explanations we told you that, to avoid distortion, like values of positive and negative grid voltage must produce equal changes of plate current and to produce this action, the tubes are operated on the straight part of the curve. To make the tube operate as a detector, we adjust the voltage values and make it work on the bend of the curve. In other words, we want distortion.

Comparing the curves of Figures 6 and 8, each have a negative grid bias of 3 volts but for Figure 8, the plate voltage has been reduced until we have but 2 MA. in the plate circuit at zero grid voltage.

As far as the A.C. signal voltage is concerned, the 3 volts negative is zero, and here again we have an A.C. wave with a maximum of 2 volts. When the A.C. grid voltage is zero, the 3 volt bias allows a plate current of but .44 MA. When the A.C. is 2 volts negative, the grid is 5 volts negative and the plate current is reduced to .12 MA. Checking up, you will find an increase of 2 volts negative on the grid reduces the plate current .32 MA.

With the A.C. signal 2 volts positive in combination with the 3 volt bias, the grid is 1 volt negative which, according to the curve, allows a current of 1.25 MA. Checking up here, an increase of 2 volts positive on the grid increases the plate current by .81 MA.

From these figures, you can see that like changes of grid voltage cause unequal changes of plate current and its wave is distorted. The changes of plate current are plotted at the lower right of Figure 8 and show the distortion very clearly.

Notice also, without an A.C. voltage on the grid, the value of plate current is at the dotted line A. When an A.C. voltage is applied, the positive alternations cause an increase of plate current greater than the reduction caused by negative alternations of equal value. For that reason, the A.C. grid voltage causes an increase of the average plate current. However, if the A.C. voltage waves are all of equal amplitude, the average plate current will remain at a constant value and therefore will not operate a speaker.

Using the curve of Figure 8 and a modulated wave similar to Figure 4C we have drawn the curves of Figure 9. Notice here that while the negative A.C. grid voltages do not reduce the plate current to zero, they cause but a small change in proportion to the positive A.C. voltages.

The result is the wave at the lower right and the average current has the same general wave form of Figure 4B. While not a perfect rectifier, the detector of Figure 9 distorts the A.C. grid voltage waves to such an extent that the changes of average plate current are at the same frequency as those which modulated the carrier wave.

GRID BIAS DETECTOR CIRCUIT

So far, we have done our explaining by means of characteristic curves but, in Figure 10, we have the circuits for producing the action of Figure 9. Like the Radio Frequency Stages explained in earlier Lessons, here we have the resonant circuit made up of coil L2 and the variable condenser C.

The C bias is secured by means of the resistor R1 and its bypass condenser C1, connected in series with the cathode circuit. In order that the tube act as a detector, values of grid bias and plate voltage are used to make it operate on the bend of the curve as explained for Figure 8.

The value of C bias voltage is governed by the amplitude of the signal voltage wave. As we explained for Figures 5 and 6, we do not want the grid positive. It is necessary therefore to have the bias voltage of a value equal to, or a little greater than, the signal voltage on the grid. The number of amplifier stages ahead of the detector will, in a great measure control the signal voltage. Then, with the proper value of grid bias, the plate voltage is adjusted until the tube operates at the proper point of its curve.

Earlier in the training, we gave you a table of tube characteristics, in which you will find the correct values of voltage on the different elements of a tube in order for it to operate as a bias detector or amplifier. By applying these voltages, the tube will operate on the desired portion of the characteristic curve.

With the tube working properly as a detector, there will always be some radio frequency current in the plate circuit. To provide a low resistance path for this radio frequency, the condenser C2 is connected from the plate to the negative return. You can think of the action here about the same as that explained for regeneration and will often find a choke coil, as well as a condenser to prevent radio frequency current from getting into the audio frequency circuits.

The modulation, or sound signal, is developed across the load resistance R2 from which it is applied to the grid of the first A.F. amplifier through a coupling condenser and grid load which form a resistance coupled stage.

GRID LEAK DETECTORS

③3 The third method of demodulation is the grid leak and condenser type, the circuits of which are shown in Figure 12. It is more sensitive than the grid bias detector because it acts as an amplifier as well as a detector. The action here is more complicated and can be best shown by means of the curve of Figure 11 where we have plotted the grid current against the grid voltage.

In our former explanations we told you there was no grid current with a negative grid voltage. However, by using an extremely sensitive meter and measuring in "Microamperes", we can plot the curve. A microampere is equal to one millionth of an ampere and as the curve of Figure 11 shows but 2 microamperes at zero grid voltage and zero grid current at 6 volts negative, for most explanations this extremely small current need not be considered.

While not exactly correct, we have drawn the curve of Figure 11 like that of Figure 8 to show that like changes of grid voltage cause unequal changes of grid current.

Looking at the circuits of Figure 12, the radio frequency voltage of the tuned circuit, L2-C, acts across the grid circuit. Tracing the grid circuit, we find the resistance R1, with condenser C1 across it, is in series with the grid. The condenser C2 is an R.F. bypass and resistor R2, the load across which the A.F. signal will appear, as explained for Figure 10.

The grid current, shown by the curve of Figure 11, will travel from the grid, to the cathode inside the tube and, to complete the circuit, back through L2 and the grid resistor R1 of Figure 12. As we have told you many times, current in a resistance causes a voltage drop. Here then, with the direction of current toward the grid, the voltage drop across R1 will make the grid negative in respect to the cathode. For the ordinary detector of this type there should be a drop of from 1 to 2 volts across R1.

At point A, Figure 11, there is a grid current of approximately 1/2 microampere and using Ohm's Law, it will require a resistance of 2,000,000 ohms for this current to cause a drop of 1 volt. For high resistances, we take 1,000,000 ohms as a unit and call it a megohm, therefore R1 of Figure 12 needs a resistance of 2 megohms to produce a one volt drop.

The value of this resistance, commonly called a "Grid Leak" determines the operating point "A" on the curve of Figure 11. The higher the resistance of the grid leak, the greater the voltage drop across it, and the more negative the operating point.

GRID CONDENSER VALUES

On account of the action inside the tube, the grid current will be in one direction only but the high frequency a-c signal voltage will cause some high frequency current. These currents can not pass through the high resistance of the grid leak therefore the condenser C1, Figure 12, is necessary as a bypass.

If the capacity of the condenser is too small, it causes a loss of radio frequency voltage and prevents the maximum signal strength on the grid.

If the capacity of the condenser is too large, the audio frequency currents, used to cause the voltage drop across the grid leak, will be bypassed. However, the common values of grid condensers are .0001mfd, .00025 mfd and sometimes .0005 mfd, capacity. The .00025 mfd size is by far the most common.

DETECTOR ACTION

Keeping all these actions in mind, the effect of the signal voltage on the grid is to cause the changes of grid current as shown in Figure 11. Like the action of Figures 9 and 10, the average value of grid current is the same as the audio frequency of the modulated carrier wave.

As the grid current increases, there is a greater voltage drop across the grid leak and thus a greater negative grid bias. This increase of negative grid voltage causes a decrease in plate current. The plate current therefore will have the same audio frequency as the grid current but will reduce as the grid current increases. ⑤

For the grid bias detector of Figure 10, the signal voltage on the grid caused an increase of plate current. For the grid leak detector, the signal voltage on the grid causes a decrease of plate current. For the grid leak detector however, the changes of grid voltage cause corresponding changes of plate current the same as explained for the amplifier tubes. ⑤

The action of the grid leak detector is often explained without any mention of grid current. Suppose the grid leak of Figure 12 is omitted. Then the condenser C1 will prevent any direct current in the grid circuit. As the signal voltage is impressed on it, the grid is first positive and then negative in respect to the cathode. While positive, it attracts electrons, but when negative there is little if any attraction.

These electrons cause the grid to be negatively charged and each time the signal voltage makes the grid positive, more electrons are attracted and the charge is increased. The condenser C1 prevents the electrons from escaping and thus the negative charge on the grid increases. The usual tube action takes place and the negative grid reduces the plate current.

If allowed to continue, the negative grid charge would increase and reduce the plate current to such a low value the receiver would not operate. The high resistance grid leak, connected across the grid condenser, forms a leakage path for the electrons, allowing them to escape and thus the grid loses its negative charge and returns to normal, or zero potential.

Being used as a leakage for the electrons, the grid leak can be connected across the condenser, as shown in Figure 12, or connected from the grid to the cathode.

SENSITIVITY

Due to its amplifying action, the grid leak detector is more sensitive than the grid bias or plate detector. The sensitivity of the grid leak detector increases up to a signal strength of about 1/5 of a volt and holds good up to the limit of the tube. The steepness or slope of the grid voltage-plate current curve determines the amplification. The steeper the slope, the greater the sensitivity.

The bias and diode detectors, while not as sensitive, have the advantage of being able to handle stronger signals without distortion. In general, you will find grid leak detectors used for weaker signal voltages but, where the signal is built up with several stages of high frequency amplification, the bias and diode detectors are employed.

POWER DETECTORS

Although used a great deal in advertising, electrically there is no exact meaning for the term, "Power Detector". A power detector uses the same type of tubes and circuits we have explained in this Lesson.

To improve the tone and reduce noises of receivers, many designers decided that but one stage of audio amplification should be used. To secure sufficient volume, the detector output had to be increased.

The power detector then is designed to handle an input signal of several volts without distortion. The difference between ordinary and power detectors therefore is only in the strength of the signals that can be handled. While both the grid leak and grid bias types are used as power detectors, the diode type is perhaps the more common. It has the natural ability to handle stronger signals and, using a high gain R.F. or I.F. amplifier, its lack of sensitivity does not affect the sensitivity of the receiver.

LINEAR DETECTION

A linear detector produces changes in output current which are proportional to the changes of input voltages. There are no perfect linear detectors because all have a certain amount of bend in their characteristic curves. For weak signals, the detection is as we have explained but, for strong signals, the action approaches "straight line" or linear detection.

The advantages of power detection are important enough to make their use worth while. By applying a stronger signal, linear detection is obtained and distortion reduced. Using but one stage of audio amplification, distortion is further reduced and because most of the amplification is at a high frequency, hum, tube noises and other interference is reduced.

AUTOMATIC VOLUME CONTROL

Automatic volume control, commonly abbreviated "A.V.C." was briefly mentioned in the earlier Lessons but, because of its application to practically all present day commercial superheterodyne receivers, we want you to have a more complete understanding of its action and therefore will spend the balance of this Lesson on the subject.

When we stop to consider the usual conditions of signal input, it is not difficult to understand why "A.V.C." has been so universally applied to radio receivers. The waves cutting the antenna of most any radio receiver installation will be of various amplitudes depending on the strength of the transmitter and their distance from the receiving station. In the case of weak carriers, the signal strength may be as low as 2 or 3 microvolts whereas with a powerful local transmitter, it may be as high as 1 volt.

Therefore, without A.V.C., tuning the receiver from a weak to a strong signal, without changing the gain or volume control, would result in a very loud, and probably distorted, sound from the speaker. However, this difficulty commonly referred to as blasting, can be minimized with automatic volume control.

Then also, as explained in an earlier Lesson, a change in the Kennelly-Heaviside Layer produces a variation of signal strength. The effect of this phenomena, commonly called "Fading" can be reduced to a low value by applying A.V.C.

Going back to the earlier Lessons on vacuum tubes, you will remember that an increase of the negative bias voltage, applied to the control grid, reduces the plate current and likewise reduces the gain or available amplification. If we express this condition in relation to the sensitivity of a receiver, rather than gain or amplification, it means that an increase in negative control grid bias, applied to the R.F. and I.F. stages of a receiver, reduces the sensitivity of the complete system.

Thus, if we devise some method of automatically changing the negative control grid bias on the R.F. and I.F. stages of a Radio receiver, in proportion to the incoming signal strength, an automatic control of the sensitivity is secured. This will provide an approximately constant signal level at the detector which, in turn, will result in a constant audio output although there is a change of signal strength in the antenna. This is the general method employed in present A.V.C. circuits and the following explanations will show you how we are able to obtain this "automatic" control of the negative grid bias voltage.

RECTIFIER ACTION

Due to the amplifying action of the radio and intermediate frequency stages of a receiver, the carrier wave has its greatest strength at the demodulator or detector. Therefore, we will investigate its action to determine if it is possible to obtain a D.C. voltage which will vary with the applied signal and be available as a negative bias to the control grids of the R.F. and I.F. stages.

Looking at Figure 13, which is a simplified arrangement of Figure 7, we have tube T1, as the last I.F. stage of a superheterodyne receiver, coupled to a diode second detector T2, by the I.F. transformer consisting of a tuned primary and secondary. As you know, the diode detector is really a rectifier and perhaps it will help you to follow our explanation by considering the secondary of the I.F. transformer as a high voltage winding of a power transformer, the tube and load resistance R, completing the circuits of a conventional half wave rectifier system.

Since we are interested in obtaining a fairly high D.C. voltage and because it is essential to apply a minimum load on the I.F. transformer, so as to reduce detuning and damping of the circuit, R has a comparatively high value, usually of the order of several hundred thousand ohms. The bypass condenser C is installed to provide a path for the intermediate frequency currents so they will not pass through the resistor R.

From the earlier explanations, you know that a diode rectifier is essentially a linear rectifier which means that an increase of input results in a proportionally greater output. For simplicity of explanation, we will assume a 2 to 1 ratio between the carrier voltage and the rectified D.C. That is, with a 10 volt carrier across the secondary L, a D.C. voltage of 5 volts will appear across the load resistor R. Thus, if the strength of carrier increases, the D.C. voltage output also increases.

However, from your study of the diode detector, you know that the voltage appearing across R, with a modulated I.F. input, is going to vary with the modulation and is therefore not steady, but pulsating D.C. In this form, it is not possible to employ it as the control voltage for A.V.C. because its variation at an audio rate, representative of the modulation component of the carrier, would be the equivalent of applying an audio signal to the R.F. and I.F. stages.

This pulsating D.C. however, is made up of two parts, or components. One part is the modulation component and the other is the steady D.C. voltage. The next step therefore is to separate these two voltages so that the steady D.C. can be made available for the A.V.C. control voltage.

The method by which these are separated is exactly the same as in any other system wherein we wish to remove the A.C. component from a pulsating D.C. voltage. You will notice that the network used for this purpose, as shown in Figure 14, is very similar to the conventional type of filter found in the normal power supply system. In comparison, resistors R1 and R2 occupy a position similar to that normally occupied by the filter chokes in a power supply and condensers C1 and C2 occupy the normal filter condenser positions. Considering all facts, the filter system employed in an A.V.C. circuit, to secure a pure D.C. output, is basically the same as the filter employed in a conventional power supply system.

ACTION OF A.V.C. FILTER

The action of the A.V.C. filter network is not hard to understand and we want you to imagine the circuit of Figure 14 is connected across the output of Figure 13. That is, point A would be connected to the lower end of L, with point B connected to ground. Thus, between points A and B there will be a steady D.C. voltage plus an A.C. voltage but, in analyzing the action, we will consider each of these voltages separately.

As we are interested in the steady D.C. voltage as a source of control grid bias, we see condensers C1 and C2 are connected so that the circuits of Figure 14 will not allow D.C. current between "A" and "B". Consequently, there is no direct current in R1 or R2 and therefore no D.C. voltage drop across them. Thus, the D.C. voltage output of the filter, between points X and Y, is equal to the D.C. voltage input between points A and B. The fact that there is no direct current through the filter system is the factor which permits the use of high resistances in place of the low D.C. resistance filter chokes used in the conventional power supply filter circuits.

In the case of the A.C. component, the action is entirely different. In the first place, the capacities C1 and C2 are chosen to have a low reactance at audio frequencies. This means that only a small A.C. voltage will be developed across the first filter condenser C1 because of its relatively low impedance with respect to the first resistance R1. This small A.C. voltage across C1 is further reduced by the same action in the R2-C2 combination with the result that very little A.C. voltage appears across C2, which is the output of the filter.

To make use of some definite quantities, we will assume R1 has a value of 1 megohm, R2, 500,000 ohms and the condensers C1 and C2 each .05 Mfd., with a reactance of 10,000 ohms at some definite frequency. To make our example simple, we will consider this reactance as a resistance and also assume that the signal input to the filter is composed of a 5 volt A.C. component and a 5 volt D.C. component.

With a 5 volt A.C. signal across AB of Figure 14, there will also be a 5 volt A.C. drop across R1-C1. Following the rule that voltage drop is proportional to the resistance, when R1 = 1,000,000 ohms and C1 = 10,000 ohms, the voltage drop across R1 will be

$$E_{R1} = \frac{1,000,000}{1,000,000 + 10,000} \times 5 = 4.95 \text{ Volts}$$

while for condenser C1,

$$E_{C1} = \frac{10000}{1000000 + 10000} \times 5 = .05 \text{ Volt}$$

As the combination C2-R2 is connected across C1, the applied voltage is .05 volt. With R2 having a value of 500,000 ohms and C2, 10,000 ohms, the drop across R2 will be

$$E_{R2} = \frac{500000}{500000 + 10000} \times .05 = .049 \text{ Volt}$$

while for condenser C2,

$$E_{C2} = \frac{10000}{500000 + 10000} \times .05 = .001 \text{ Volt}$$

Thus, the filter system has attenuated the A.C. component so that at the output of the filter, the A.C. voltage is equal to about 1/5000 of the A.C. voltage present in the input of the system.

To continue our explanation, the filter has no effect upon the D.C. of the detector output, which is the part we seek for automatic volume control purposes. Inasmuch as we have stated there is no direct current through the filter, the D.C. voltage across the output is approximately equal to the input which, in this case, is 5 volts.

Although the above explanation is correct for a definite condition, in actual practice the filter system must be capable of separating the A.C. and D.C. components for all frequencies in the audio spectrum. You know the reactance of a condenser varies inversely with the frequency and therefore, at the lower end of the audio band, the efficiency of the filter described above will be reduced because the ratio of reactance to resistance will be reduced. That is, the reactance of the filter condensers will increase while the ohmic value of the resistors will remain approximately the same. As the voltage drop across the circuit is in proportion to the resistance and reactance, the drop across the condenser will increase, allowing a greater A.C. voltage at the output of the filter.

However, at the higher frequencies, the efficiency of the filter will be increased due to the reduction of the capacity reactance of the filter condensers. This gives a lower voltage drop across C1 and C2 of Figure 14 and therefore, a lower A.C. voltage at the output of the filter.

In analyzing this, one's first thought is that the values of the filter components should be so chosen as to give good efficiency at the low audio frequency. This would, of course, mean increasing the capacity of C1 and C2 or increasing the values of the filter resistance R1 and R2. A design of this type would give the desired D.C. component but, at the same time, would slow up the "speed of action" of the A.V.C. system. In other words, the time delay of the system would be too great for efficient "A.V.C." action and therefore a compromise between filtering efficiency and time delay must be made in the practical design.

By the addition of the filter of Figure 14 to the output of Figure 13, we have available a steady D.C. voltage which will vary in value with the applied modulated I.F. voltage. So far, we have said nothing about the polarity of this voltage but by checking the circuit of Figure 13 and considering the direction of current to be from plate to cathode, the voltage drop across R will be positive at the cathode and negative at the end connecting to the I.F. transformer. Therefore, with the filter of Figure 14 connected as before, point X will be negative in respect to point Y or ground.

With a 10 volt I.F. signal applied to T2, Figure 13 and assuming a 2 to 1 ratio between the applied voltage and D.C. output, there will be a 5 volt drop across R. With the filter properly connected, and no D.C. current, point X of Figure 14 will be 5 volts negative in respect to point Y. If the I.F. signal is increased to 50 volts, then point X will be 25 volts negative in respect to point Y.

Thus, we have accomplished what we set out to do and that was to obtain a negative voltage which would be automatically controlled by the strength of the modulated carrier. If the control grid of a tube were connected to point X of Figure 14, with the cathode connected to point Y, its bias voltage would increase or decrease with the strength of the carrier voltage and its sensitivity or gain would be automatically controlled.

A.V.C. CIRCUIT

Now that we have explained the action of the A.V.C. rectifier and filter, in Figure 15 we have the complete circuit showing the connection to the grid of a tube controlled by A.V.C. In checking through this circuit, you will notice that we have combined Figures 13 and 14 and have added the grid and cathode circuits of T1.

In the cathode circuit of T1, Figure 15, we have the resistor R3 with its bypass condenser C3. The control grid circuit of T1 is from the upper end of the I.F. transformer secondary L, through R2, R1, R to ground, and is completed from ground through R3 to the cathode. Thus, with no signal input to operate the A.V.C., there will still be a bias voltage on the control grid due to the voltage drop across R3 caused by the plate and screen currents of T1.

With adequate capacity in C3, the voltage drop across R3 can be assumed as constant and therefore the negative bias on the control grid of T1 will not be lower than the drop across R3. This may bring to your mind a question as to the necessity of this minimum bias voltage but, you must remember that most tubes operate at their maximum efficiency with a definite bias voltage. Therefore, the ohmic value of R3 is chosen so as to give the required voltage drop for maximum sensitivity of the stage. Used in this way, the voltage drop across R3 is commonly referred to as the "initial" bias voltage. To illustrate with definite values, we will assume this drop to be 3 volts, giving an initial negative bias of 3 volts on the control grid of T1.

Now let's see what happens when a carrier voltage from the secondary L is impressed on the control grid of T1. As T1 is an I.F. amplifier tube, the signal will be amplified and appear in the plate circuit which contains L1, the primary of the I.F. transformer. Because of the inductive coupling, the signal voltage will appear across the secondary L2 and be impressed on the detector T2 and resistance R. Let's assume this signal has an amplitude of 10 volts and, with a 2 to 1 ratio, there will be a 5 volt steady D.C. component across R.

As "R" is in its return circuit, this voltage is applied to the control grid of T1 and it will be 5 volts negative in respect to ground. However, the cathode is the reference point of the tube and we must consider the voltage drop across R3. Checking the polarity of the voltage drops across R3 and R1, you will notice they are in series and thus the negative bias on T1 is now 5 + 3 or 8 volts, resulting in a reduction in the sensitivity of the I.F. stage.

From the above explanation, you can see that the A.V.C. action tends to maintain a uniform output from the detector regardless of the signal strength at the input of the receiver. A.V.C. action is not perfect and the output of the detector is not the same for all values of input. However, a receiver equipped with A.V.C. is far superior in operation and constant output than one without this feature. By distributing the steady D.C. voltage output of the A.V.C. filter to the control grids of several tubes, the desired degree of control over the amplification in the R.F. and I.F. systems is obtained.

DELAYED A.V.C. SYSTEMS

The simple A.V.C. system of Figure 15 becomes effective in reducing the gain of the I.F. or R.F. stages even on the weakest signals and therefore is really a disadvantage at low input signal levels. To overcome this defect, a little different design has been developed which, because of its action, is called "Delayed A.V.C.".

Fundamentally, the action of a delayed A.V.C. system depends upon the fact that the generation of the A.V.C. voltage is "delayed" until the input signal to the receiver reaches a certain predetermined value. As an example, we can say that the simple A.V.C. will operate at all signal levels above 1 microvolt while the delayed A.V.C. will not function until the level is greater than 50 microvolts. Therefore, with delayed A.V.C., the receiver will operate at its maximum efficiency on all signals of less than 50 microvolts. Using the simple system, the A.V.C. will be operative at all signal strengths and thus reduce the sensitivity of the receiver on weak signals.

These actual values are given only as an illustration and should not be considered as standards for receivers which employ delayed A.V.C. systems. You will find some receivers which operate over these limits, others designed so that the A.V.C. functions at less than 50 microvolts input and still others at more than 50 microvolts input.

The value of signal strength, at which the A.V.C. starts to function, is known as the threshold voltage. For values of input below the threshold voltage, the receiver will operate at its maximum sensitivity, as the initial bias voltage is the only negative voltage on the control grid.

To show you just how this delayed action is accomplished, in Figure 16 we show the conventional circuits of a delayed A.V.C. system. Checking through the circuits, you will find an I.F. amplifier tube T1 and a duo-diode T2, which functions as a second detector, or demodulator, and A.V.C. rectifier. In reality, T2, consists of two half wave rectifier tubes in one envelope.

Following the signal through the demodulator, we start with coil L, go to the control grid of T1, to the plate and then through the I.F. transformer windings L1 and L2, the output of which is applied to plate, D1, of tube T2 and condenser C5. From the plate D1, the circuit is completed through the cathode, R4, back to the lower end of L2. The condenser C4 provides a low resistance path for the intermediate frequencies and thus allows the audio component to develop a voltage drop across R4, which is shown as a potentiometer and the source of the audio signal, as explained earlier in this Lesson.

Forgetting the signal for the time being, let's trace the circuit of the other half wave rectifier of T2. Starting at the plate "D2", we find it connected to one side of C5, which is considered as the source of the signal voltage, and also to R, the lower end of which is connected to ground, the circuit being completed through R5 to the cathode.

Now, notice that R5, R6 and R7 form a voltage divider from B+ to ground and as the cathode is connected to a point between R5 and R6, it must have a positive potential in respect to ground. With zero current in R, the plate, D2, is at ground potential and will be negative in respect to its cathode.

From your study of vacuum tubes, you know the plate should be positive, in respect to the cathode and therefore, with a negative plate, there will be no plate current. In order to have current in the plate circuit of D2, the signal must develop a plate voltage greater than that on the cathode and when this occurs, the path of the current will be from the plate D2, to the cathode, through R5 and R to complete the circuit.

With current in this direction, the polarity of the voltage drop across R will be positive at the ground and negative at the upper end. The control grid circuit of T1 is completed through the filter system of R1, R2, C1 and C2, from the negative end of R to ground and back to the cathode through R3. Thus, it will be controlled by the A.V.C. action only when the carrier signal on the plate D2 exceeds the "delaying voltage" applied to the cathode and there is current in R.

When the conditions are such that the input signal is not great enough to overcome the "delaying voltage", the tube T1 will be negatively biased only by the drop across R3 and thus operates at its maximum efficiency. As we previously stated, the magnitude of the "delaying" voltage will depend on the design and will vary in different receivers.

NUMBER OF TUBES CONTROLLED BY A.V.C.

In our previous explanations, we told you that the tubes controlled by A.V.C. were in the R.F. and I.F. stages. However, we said nothing about the number which were to be controlled and can add now that there is no definite set rule. In some receivers of low sensitivity, only one tube will receive the control voltage while in others of high sensitivity, as many as four tubes may be automatically controlled.

This variation is due to a definite relationship between the number of tubes automatically controlled and the performance of the A.V.C. system with respect to a uniform audio output.

To show you this relationship, we will assume a certain receiver in which only one tube is controlled by A.V.C. In this case, we will say that a 2 to 1 increase in voltage output will be accompanied by a certain control voltage that will decrease the sensitivity of the receiver by a definite amount. The exact amount depends upon how much the gain of the controlled stage is influenced by the control voltage.

Now, if in this same receiver two tubes, instead of one, are controlled, then the increased signal output required to produce the same 2 to 1 voltage increase in output will have to be much greater. This is so because the sensitivity of the receiver is less than in the first case, as the gain of two tubes has been cut down.

As a general rule, you will find the large receivers, with high sensitivity, employ A.V.C. on several stages while in the smaller receivers, with low sensitivity, only one or two stages will be controlled.

We have now explained the action of the principal circuits found in the common types of Radio Receivers and therefore, for our next Lesson will show you how they are combined to make complete units which are used in Automobiles and D.C. or A.C. house lighting circuits.

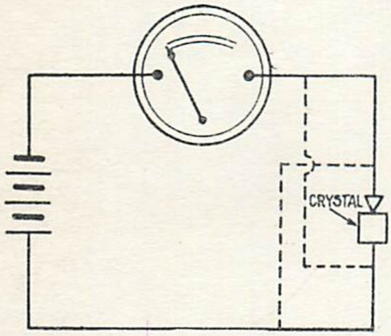


FIGURE 1

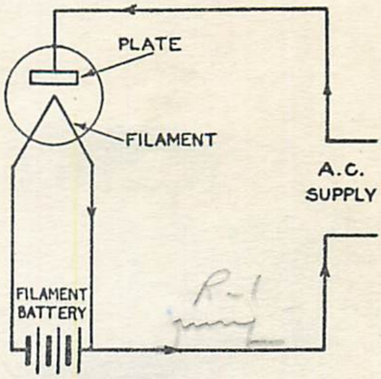


FIGURE 2

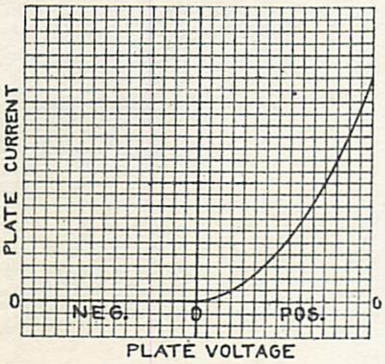
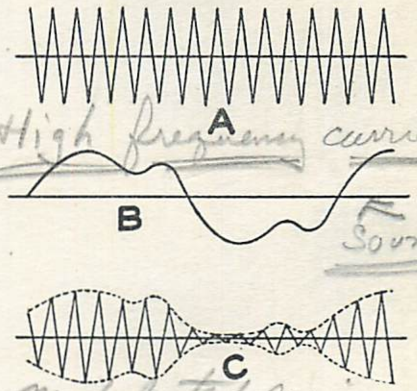


FIGURE 3



High frequency carrier wave

Sound Wave

Modulated carrier wave.

FIGURE 4

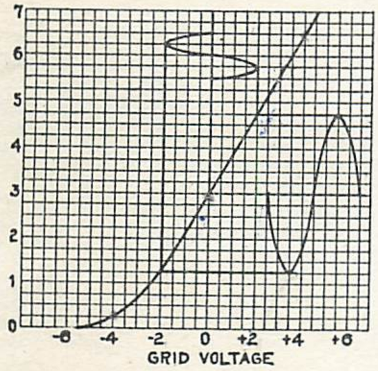


FIGURE 5

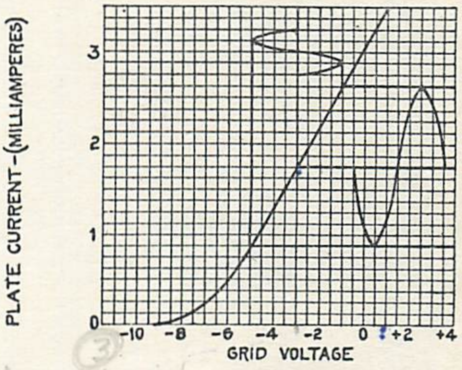
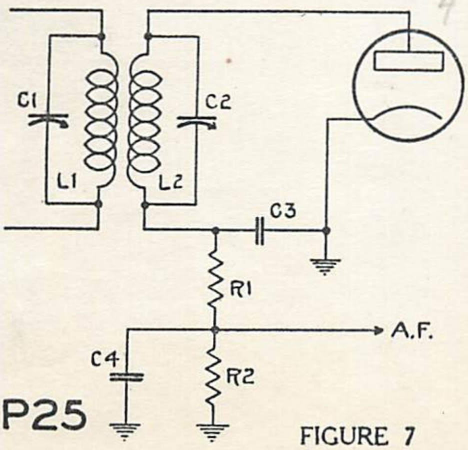


FIGURE 6

③

1/4 ma. to 6 1/2 ma.



P25

FIGURE 7

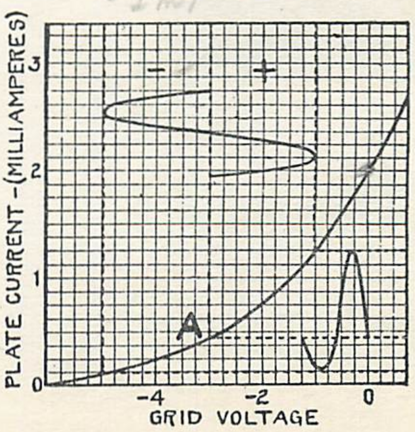


FIGURE 8

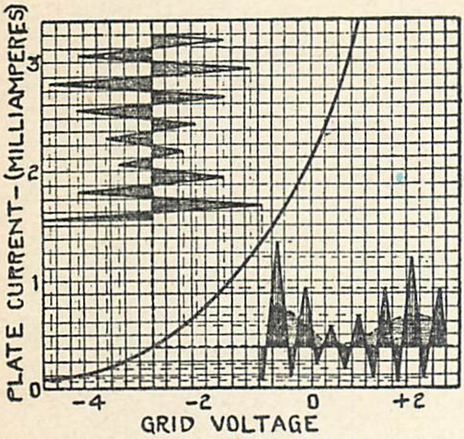


FIGURE 9

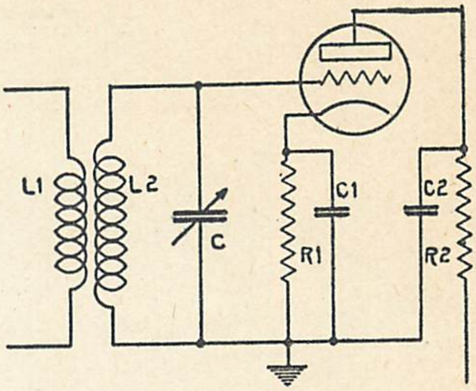


FIGURE 10

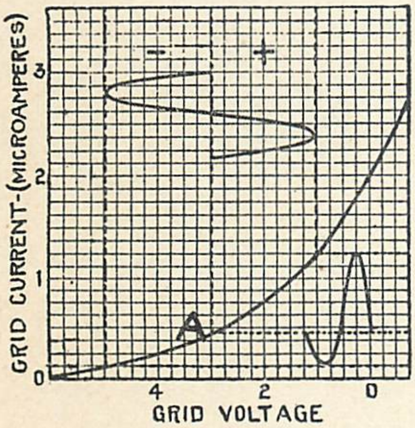


FIGURE 11

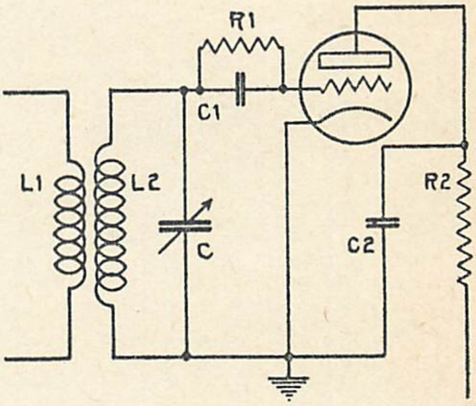


FIGURE 12

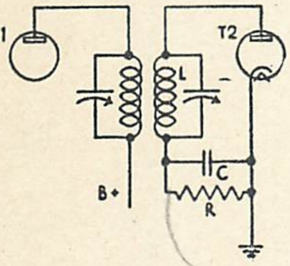


FIGURE 13

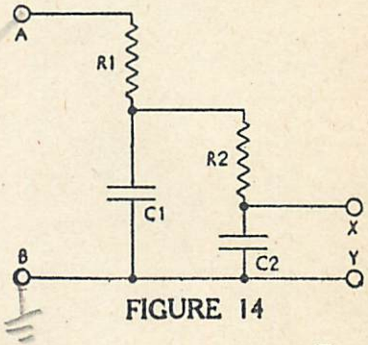


FIGURE 14

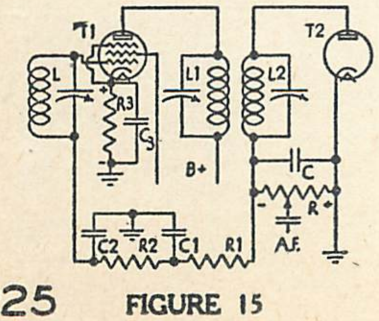


FIGURE 15

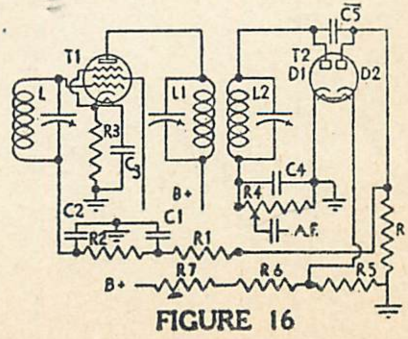


FIGURE 16

QUESTIONS AND ANSWERS

1. What is the direction of plate current in a diode tube?
   In a diode tube the direction of current is from the plate to the filament.

2. If a 4 volt A.C. is applied to the grid of Figure 5, between what values will the plate current vary?
   With 4 volts A.C. on the grid of Figure 5, the plate current will vary from .25 M.A. to 6.5 M.A.

3. What are the three methods of producing detector action?
   The three methods of producing detector action are the "Diode", "Grid Bias" and "Grid Leak and Condenser".

4. Why is a bypass condenser used in the plate circuit of a detector tube?
   A bypass condenser is used to provide a low resistance path for the radio frequency current in the detector plate circuit.

5. Does the plate current increase or decrease when an A.C. voltage is applied to the grid of a grid leak detector?
   When an A.C. voltage is applied to the grid of a Grid Leak detector, the plate current will decrease.

6. What are the advantages of power detection?
   Power detection reduces distortion, reduces hum and other noises and thus improves the tone.

7. What is the purpose of A.V.C.?
   The purpose of A.V.C. is to maintain an audio signal of uniform strength, regardless of the strength of the carrier.

8. How does the A.V.C. action tend to control the sensitivity of a receiver?
   By varying the negative grid bias on one or more of the tubes preceding the demodulator, A.V.C. tends to control the sensitivity of the receiver.

9. What is the purpose of an A.V.C. filter?
   The purpose of an A.V.C. filter is to separate the output of the A.V.C. rectifier so that its D.C. component is available as a negative bias voltage.

10. What is the main advantage of delayed A.V.C. over simple A.V.C.?
    The main advantage of delayed A.V.C. is that it is inoperative at weak signal inputs.